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# READY-USE LOW-CARBON STEEL MECHANICAL COMPONENT FOR PLASTIC DEFORMATION AND METHOD FOR MAKING SAME

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The invention relates to low-carbon steel mechanical components with elevated characteristics, such as wheel swivel joints of terrestrial vehicles, pins, shafts, suspension bars, links, or other ready-for-use analogous mechanical components obtained by plastic deformation of a long steel product (wire, rod...).

### 2. Background Art

It is known that steels for plastic deformation must exhibit characteristics of both deformability and strenght. Thus, during the manufacture of mechanical components for which some of them are intended, they have to be able to endure major changes in shape without rupture, and at times exhibit good mechanical properties in the finished product. In fact, in certain cases, the required properties of the components obtained from these steels are close to those of Class 10.9 according to Specification ISO 898, i.e. a minimum tensile strength of 1000 MPa and a minimum yield strength of 900 MPa. Moreover, these steels must exhibit good machinability characteristics, as a majority of the applications requires a final finishing to meet the end dimensions.

It should be noted that plastic deformation operations are carried out on blanks that result from cut wires or rods that have usually been obtained by hot rolling semi-finished products from continuous casting (billets or blooms). For cold plastic deformation (stamping, forging...), the blanks are shaped cold in a press, optionally after a spheroidiziation annealing step , and the resulting components are then thermally treated by quenching and tempering operations. By hot forging, the blanks are first reheated to a temperature of about 1000-1200°C, shaped whilst hot and cooled down. The resulting components are then thermally treated by quenching and tempering operations, the tempering operation being able to be done immediately on cooling after forging.

All these various heat treatments require procedures, which although understood, are still costly and which do not always meet the objectives. In any respect, they increase production time and costs.

In consequence, over the last years, a search effort has been made for grades of steel that can obviate this, so as to enable the production of "ready-for-use" components of elevated characteristics, that can be used for the designated application without having to be subjected to a heat treatment in order to modify their metallurgical structure after the plastic deformation step.

With regard to cold stamping, for example, it is already known to make use of steel grades with an essentially bainitic structure (i.e. comprising more than 50% bainite), which exhibits a good compromise between deformability and final mechanical properties. Nevertheless, due to the level of cooling capabilities generally available on a hot rolling mill, these grades only allow an essentially bainitic structure to be obtained with rolled wires or rods of relatively small diameter, in fact rarely exceeding 8 mm. Above this, one obtains a degraded bainite or bainite associated with ferrite, leading to a drastic reduction in mechanical properties of the rolled products. Furthermore, since the structure is not well controlled, there is a risk of a wide dispersion of the mechanical properties within the same reel of wires or between several reels of wire or between several rods or in the same rod at the end of the hot rolling.

Similar problems have been encountered with hot-forging steel grades, where the thickness of the forged component often imposes severe constraints on cooling in order to meet the cooling rate at the core, required for obtaining the aimed bulk bainitic structure. In addition, as the periphery of the component is inevitably cooled much more vigorously than the core, internal stresses result which can lead to unacceptable permanent deformations.

Hence, for applications involving grades for plastic deformation, searches have traditionally been made for a bainitic structure, which offers a good compromise between deformability and mechanical properties, as well as a good machinability. In all cases, success in obtaining this bainitic structure is dependent on the constraints associated with cooling the core of the steel, whether this cooling happens before or after the plastic deformation. These constraints imposed on the cooling are so severe for the presently known grades of steel used, that the bainitic structure can not always be obtained directly in the conditions of the rolling process, nor even after forging, with the result that numerous mechanical components must be subjected to a heat treatment after forming.

**OBJECTS AND SUMMARY OF THE INVENTION**

The object of the invention is to provide converters with a grade of low-carbon steel, capable of developing a bainitic or essentially bainitic structure with few constraints regarding cooling, for the manufacture of ready-for-use components by both cold stamping and hot forging.

More specifically, the object of the invention is to develop a grade of low-carbon steel specifically for the manufacture of mechanical components possessing a bainitic or essentially bainitic structure, which can be already obtained with low cooling rates at the core – as low as 1°C/s – and offering not only good deformation properties, but also a good machinability for the manufacture of components by cold or hot deformation, without a heat treatment after forming, said grade having high mechanical properties such that said components will meet the quality requirements of Classes 8.8 to 12.9 of ISO specification 898.

Therefore, an object of the invention is a ready-for-use, low-carbon steel, mechanical component with good characteristics, obtained by plastic transformation of a rolled, long steel product, characterized in that:

- the composition of said steel, apart from the iron and the unavoidable, residual impurities that result from the steel process, complies with the following analysis, given in percentages by weight, based on the iron:

$C \leq 0.15\%$
$0.04\% \leq Nb \leq 0.10\%$
$0.001\% \leq B \leq 0.005\%$
$0.15\% \leq Mo \leq 0.35\%$
$1.3\% \leq Mn \leq 2.0\%$
$0.15\% \leq Si \leq 1.30\%$
$0.01\% \leq Al \leq 0.08\ \%$
$N \leq 0.015\%$ with $Ti \geq 3.5\ x\%\ N$;

- said long product being obtained from a semi-finished product from continuous casting and hot-rolled in the austenitic range, then treated thermally to obtain a bainitic or essentially bainitic structure, and formed by a cold or hot plastic transformation into its final shape, exhibiting a tensile strength at break greater than 800 MPa.

In a first preferred embodiment, the steel, mechanical component deformed by a cold process defined above, is characterized in that the long product, from which it is derived by plastic transformation, is a rolled wire or rod, treated thermally by cooling during the rolling process, at a cooling rate sufficient to provide it with a bainitic or essentially bainitic structure.

In a second preferred embodiment of the invention, the steel mechanical component, hot forged as defined above, is characterized in that the long product, from which it is derived by plastic transformation, is a rod or a rolled wire, whose forged blank (extracted there from) was treated thermally by quenching at a cooling rate sufficient to provide it with a bainitic or essentially bainitic structure through to the core, this from a quenching temperature of about 1200°C and more, at which the blank was subjected to a plastic transformation by forging, bringing it to the final desired shape.

Preferably, in the two embodiments mentioned above, the heat treatment used in the manufacture of the mechanical component comprises a final slow cooling step, whose rate can be as low as 1°C/s at the core.

It should be noted that said cooling of the component is a mild cooling, different in all respects from a cooling step for quenching the steel, which anyway would be followed in normal practice by tempering.

In one variant, the mechanical component is made with a steel whose carbon content is comprised between 0.06% and 0.10%.

In another variant, the mechanical component is made with a steel whose molybdenum content does not exceed 0.30% and a manganese content of less than 1.80%.

Another object of the invention is a process for manufacturing a ready-for-use, low-carbon steel, mechanical component with good characteristics, exhibiting a tensile strength at break of more than 800 MPa, characterized in that it comprises the following steps:

- starting from a low-carbon steel, long, semi-finished product whose composition, apart from the iron and the unavoidable, residual impurities that result from the steel process, at least complies with the following analysis, given in percentages by weight, based on the iron:

$C \leq 0.15\%$

$0.04\% \leq Nb \leq 0.10\%$

$0.001\% \leq B \leq 0.005\%$

$0.15\% \leq Mo \leq 0.35\%$

$1.3\% \leq Mn \leq 2.0\%$

$0.15\% \leq Si \leq 1.30\%$

$0.01\% \leq Al \leq 0.08\ \%$

$N \leq 0.015\%$ with $Ti \geq 3.5\ x\%\ N$;

a long product is rolled in the austenitic range according to the customary practice of hot-rolling;

- the resulting long, rolled product is then treated thermally, this heat treatment comprising a final phase of slow cooling at a rate that can be as low as approx. 1°C/s at the core, to obtain a bainitic or essentially bainitic structure, and said long product is subjected to plastic deformation into its final shape, the plastic deformation step being able to be carried out after or during said heat treatment.

A further object of the invention is a long steel product intended for transformation into a steel mechanical component such as defined above, characterized in that it has the shape of a hot-rolled wire or rod and that the steel, which forms it, at least complies with the following analysis, given in percentages by weight, based on the iron:

$C \leq 0.15\%$

$0.04\% \leq Nb \leq 0.10\%$

$0.001\% \leq B \leq 0.005\%$

$0.15\% \leq Mo \leq 0.35\%$

$1.3\% \leq Mn \leq 2.0\%$

$0.15\% \leq Si \leq 1.30\%$

$0.01\ \% \leq Al \leq 0.08\ \%$

$N \leq 0.015\%$ with $Ti \geq 3.5\ x\ \%\ N$.

As one understands, the essential characteristics of the invention consist of the definition of an analysis of a low-carbon steel, based on niobium, boron and molybdenum, which is specific to mechanical components with elevated characteristics and capable of developing a homogeneous bainitic (or essentially bainitic) structure in the mass of the component with few constraints regarding cooling. Effectively, this structure can already be obtained by means of a low rate of cooling at the core which can be as low as about 1°C/s, the latter being a rate that can be achieved, as one knows, directly in the as-rolled conditions of rolling for wires and rods with a diameter of the order of 20 mm and more, depending on the installations.

Consequently, the invention opens up production for the line of hot-rolled long products of large diameters, destined for stamping workshops or cold forges, and for those allotted to hot forges, it saves an additional final heat treatment of quenching/tempering. To clarify still further, it should be noted that for typical as-rolling conditions, the limits of diameters are about 20 to 25 mm for the grades according to the invention.

The vocabulary habitually employed in the steel industry defines

- "wires or small rods" as rolled products with diameters up to about 30 mm (which are often packaged in the form of reels for delivery to the users);
- and "rods" as those rolled with diameters above 18 mm and which are delivered in straight bundles after having been cut to size at the end of the line.

Moreover, with the aim of clarifying the description, the expression "bainitic structure" refers to a "bainitic or essentially bainitic structure".

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)**

The invention will be well understood and other aspects and advantages will become more clear from the following detailed description, presented as an example of reduction to practice.

In a steel works, continuous casting produces long, semi-finished products (billets and blooms) from a steel having, apart from iron, the following composition by weight, based on the iron:

From 0.02 to 0.15 %, and preferably 0.08 % of carbon. At these levels, carbon produces a bainitic structure with the required mechanical properties. It affords a good aptitude towards strain hardening during cold plastic deformation. Its low level also avoids any formation of large carbides that are unfavorable to ductility, without the need for any treatment of spheroidization.

From 0.04 to 0.10 %, and preferably between 0.06 and 0.08%, of niobium. Niobium acts in synergy with molybdenum and boron to extend the range of bainitic conversion. It increases the quenching effect of boron by increasing the active boron content in the steel. Indeed, the formation of carbides $Fe_{23}(CB_6)$ (trapping the boron and passive towards the steel quenchability) is made more difficult under the influence of niobium, which stabilizes the austenite and delays the diffusion of carbon. Moreover, it

increases the crystallization temperature of the austenite, thus promoting the appearance of a more finer bainitic structure during controlled rolling, and thereby increases the resilience of the components.

From 0.001 to 0.005 % of boron. Boron inhibits the germination of ferrite, thereby promoting the formation of a bainitic structure. It acts in synergy with niobium and molybdenum to extend the bainitic range.

From 0.10 to 0.35 %, and preferably less than 0.3 % of molybdenum. Molybdenum is a carburigenic element enabling the bainitic range to be extended by retarding the germination of ferrite. In addition, at these levels, its action on the quenchability of the steel enables a steel to be obtained with a superior mechanical resistance by lowering the onset temperature of the bainitic conversion. It thereby tends to compensate for the low carbon content required to obtain a good ductility. Moreover, it acts in synergy with boron and niobium by reinforcing their action. In addition, at these levels, it acts in synergy with niobium to increase the recrystallization temperature of the austenite.

From 1.30 to 2.00 %, and preferably between 1.60 and 1.80 % of manganese. Manganese also enables an adequate quenchability, facilitates the formation of bainite and enables the mechanical properties to be obtained.

From 0.10 to 1.30 %, and preferably from 0.20 to 0.35 % silicon. At these levels, it facilitates a moderate hardening of the steel. If necessary, the level may be increased to 1.30 %, particularly for increasing the mechanical strength of the steel. Silicon also enables the steel to be deoxidized during the casting.

From 0.007 to 0.010% of nitrogen, together with a titanium content of the order of 3.5 times this nitrogen content, in order to make a sacrificial shield in favor of boron. Titanium fixes nitrogen and thereby protects the boron. Without titanium, the boron would lose its quenching power by reacting with the nitrogen. Titanium also permits the formation of a fine austenitic grain, thereby improving the cold shaping and the ductility.

Less than 0.08 % aluminum. This residual, dissolved aluminum, resulting from the steel killing prior to casting, is a good deoxidizer to protect the titanium against oxidation by the unavoidably present dissolved oxygen, so that the titanium remains available to protect the boron against nitrogen. This aluminum also serves to control the enlargement of the austenitic grain during hot rolling of the semi-manufactured starting product, thereby lending good resilience properties to the steel.

Possibly 0.001 to 0.1 % sulfur. This sulfur combines with manganese, forming plastic and ductile manganese sulfides. It enables a good machinability. Should the machinability need to be increased further, it is possible to increase the sulfur content up to a maximum of 0.1%, but no greater, in order to retain good cold deformation properties.

This steel also contains the unavoidable impurities and residual elements resulting from its manufacture, notably phosphorus, the content of which should preferably remain less than 0.02%, to guarantee a good ductility prior to and after the cold forming, as well as copper and nickel, whose contents should preferably be less than 0.30%.

This optimized composition enables the steel to have a very good aptitude for plastic deformation as well as a good machinability. In fact, this grade not only favors the formation of bainite, but also reduces the risk of forming martensite, whose presence can constitute a serious obstacle to a good machining step.

Incidentally, most of the time, the molybdenum content can be limited to 0.30% and that of manganese to 1.80% in order to obviate any risk of a quench structure of the martensite type appearing in certain cases due to the local conditions.

One essential aspect of the invention is that the mechanical components exhibit a homogeneous bainitic structure in the mass with a low rate of cooling (that can be as low as about 1°C/s) at the core of the hot-forged components, or of the wires or rods that are made from them by cold stamping.

When, in accordance with the practice of the invention, the mechanical component is cold stamped (or cold forged), the bainitic structure is obtained prior to shaping. Then, after deformation, the steel possesses a good ductility, measured by a reduction in cross-section largely superior than 50%, a tensile strength greater than 650 MPa, and a mechanical strength greater than 800 MPa.

In this first embodiment, the component is actually obtained by cold plastic deformation of the steel, which already exhibits a bainitic structure. A long semi-finished product, constituted by steel whose analysis conforms with the invention, is supplied and hot-rolled, if needed after reheating above 1100°C, using the customary hot-rolling technique until a rolled wire is obtained with a diameter of 10 mm, for example. The removal temperature of the wire is less than 1000°C.

The resulting rolled wire is then cooled in air in the terminal area of the rolling mill itself, according to the customary manner ("Stelmor Process", for example) at a low rate at the core, which can be as low as approx. 1°C/s, to obtain a homogeneous bainite structure.

The rolled wire is then delivered (or deliverable) to the converter customer in the form of a reel. The converter who receives the reel of wire, straightens it out if needed, before cutting it up into blanks of the required length. Each blank is then subjected to the customary step of cold plastic deformation so as to obtain the final ready-for-use component (swivel joints, shafts, links, pins...) after machining to size, when needed. The final mechanical properties are obtained naturally by the annealing, resulting from the shaping.

In a second embodiment, the component is deformed hot and the bainitic structure is obtained after this step of plastic deformation: a long semi-finished product,

constituted by steel, whose analysis conforms with the invention, is supplied and hot-rolled until a rolled rod is obtained with a diameter of 30 mm, for example. After optional cooling, the rod is cut up into lengths and is deliverable in straight lengths to the forge with its ordinary metallurgical structure resulting naturally from the hot rolling.

The smith customer who receives it cuts it up into blanks and each blank is then brought to a temperature of about 1200°C before being subjected to a step of hot plastic deformation in the forge. The components are then cooled in the customary manner, in two steps, with a first controlled cool down to a temperature of less than 1000°C and a second cool at a low cooling rate at the core, which can be as low as approx. 1°C/s. In this embodiment, the conditions at the end of rolling are not particularly important for the resulting metallurgical structure, because the bainite, which lends the component the crux of its end-use properties, is realized after the hot shaping and the controlled cooling.

It should be remembered that the mechanical components according to the invention are obtained by plastic deformation of rolled products without additional heat treatment of quenching and tempering.

Laboratory tests were carried out on a casting of the following composition:

| %C | %Mn | %Nb | %Cr | %B | %Mo | %Ti | %$N_2$ | % Si | %S | %Al |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.08 | 1.6 | 0.08 | 0.2 | 0.003 | 0.2 | 0.029 | 0.006 | 0.25 | 0.004 | 0.028 |

The billets from the casting were hot rolled after reheating above 1100°C, to form a wire of 12 mm in diameter. The removal temperature of the wire after rolling was 820°C. The rate of cooling of the wire in the terminal area of the rolling mill (cooling by blown air of the "Stelmor" type) was the order of 5°C/s. A homogeneous bainitic structure was obtained for the whole wire on its periphery as well as at the core.

The mechanical properties of the wire were as follows:

| Rm (MPa) | $Rp_{0.2}$ (MPa) | A (%) | Z (%) |
|---|---|---|---|
| 857 | 683 | 17.4 | 71.4 |

It should be noted that

- Rm stands for the mechanical break strength corresponding to the maximum force before break, reported for the initial cross-section of the wire.
- $Rp_{0.2}$ stands for the conventional yield point corresponding to the force, reported for the initial cross-section of the wire, which causes a plastic elongation of 0.2%.
- A stands for the elongation at break.
- Z stands for the reduction in area corresponding to the reduction in cross-section of the wire after rupture.

The change in mechanical properties as a function of deformation of the wire is as follows:

| Reduction (%) | Rm (MPa) | $Rp_{0.2}$ (MPa) | A (%) | Z (%) |
|---|---|---|---|---|
| 20 | 960 | 885 | 13.7 | 67 |
| 35 | 1030 | 982 | 13 | 65.5 |
| 50 | 1100 | 1020 | 11.5 | 61.5 |
| 60 | 1160 | 1115 | 10.8 | 60.5 |
| 75 | 1265 | 1220 | 10.6 | 57.7 |

The mechanical components with good characteristics according to the invention are remarkable in that, in particular, they allow the quenching and tempering treatments, which are actually carried out during stamping or cold forging or hot forging, to be dispensed with.

Moreover, by imposing less drastic cooling conditions, there is less risk of deformation during the cooling operation, or put another way, for the same cooling fluid, they can have greater diameters or thicknesses.

They are also remarkable in their very good machinability characteristics, permitting a reduction of sulfur for cold processing steps and therefore limiting the detrimental influence of this element on the deformability.

Obviously, the invention should not be limited to the examples, which have just been described, but should extend to a plurality of variants and equivalents, as defined by the claims presented below.

Accordingly, e.g. for applications in hot forging, the person skilled in the art can choose to improve the machinability by varying the sulfur content or by adding other agents that improve the machinability, such as tellurium, lead or selenium.

Similarly, although the invention is more particularly directed to applications of stamping or cold forging or hot forging, it also applies to other applications of plastic deformation, such as wire drawing, deep drawing, stamping, etc...

**WHAT WE CLAIM IS:**

1. A ready-for-use low-carbon steel mechanical component with elevated characteristics obtained by plastic transformation of a laminated long steel product, wherein:

- the composition of said steel, apart from the iron and the unavoidable residual impurities that result from the steel process, complies with the following analysis, given in percentages by weight, based on the iron:

$C \leq 0.15\%$

$0.04\% \leq Nb \leq 0.10\%$

$0.001\% \leq B \leq 0.005\%$

$0.15\% \leq Mo \leq 0.35\%$

$1.3\% \leq Mn \leq 2.0\%$